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Estimates of Nitrate Leaching from Wheat Fields in Gorgan, of Iran

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Abstract: There is no estimation on the nitrate leaching from arable lands of Iran. Therefore, the CERES-wheat of DSSAT model was used to estimate the nitrate leaching from wheat fields of Gorgan. The experiment was conducted in Gorgan Northeast of Iran, during 2005-2007 years. Input data were 3 nitrogen use scenarios (N-S), 3 soil profiles (SLPs) and two Cropping Systems (CS) including rainfed (RFD) and irrigated (IRR) as well as daily weather data of this area. The amounts of fertilizer-N used in N-S-1, N-S-2 and N-S-3 were 165, 122 and 96 kg N ha^{-1}, respectively. Three SLPs were defined on the basis of the analysis of hundreds soil samples. Soil samples were taken from arable lands to a 120 cm depth. The simulations were performed for a 45 years time period from 1961-2006. The average of N-leached in scenarios during 45 years estimated to be 23.6 kg N/ha/year. Cropping system and SLP had significant effects ($p = 0.01$) on the nitrate leaching, but the effects of N-Ss and interactions between 3 factors were not significant, statistically. The results of simulations indicated that in RFDCS and IRRCS about 16 and 31 kg N/ha/year have been leached, respectively. The N-leached rates from SLP I, II and III were 39, 19 and 13 kg N ha/year, indicating significant differences between SLPs. It can be concluded that considerable amounts of nitrate-N are leached from wheat fields in Gorgan, annually that can have important economic and environmental impacts.

Key words: Nitrate leaching, DSSAT model, fertilizer N, soil profiles, wheat

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INTRODUCTION

Synthetic N fertilizers are used in large quantities to meet the nitrogen (N) demands of crops including wheat. NO_3-N is particularly susceptible to leaching due to high water solubility. Plant uptake and microbial immobilization can not remove the entire NO_3-N from soil. Therefore, a noticeable portion of nitrate can be moved to lower layers of soil profile and reaches finally to water resources in regions where farmers use the excessive N fertilizers (Strebel *et al*., 1989; Ragab *et al*., 1996; Groffman, 2000; Helwig *et al*., 2002; De Paz and Ramos, 2004).

In many regions, agriculture is a major source of diffuse N pollution to surface water and groundwater (Kronvang *et al*., 1996; Granlund *et al*., 2005; Liu *et al*., 2005; Mathers *et al*., 2007). The challenge of agriculture-derived nitrate pollution of water resources is particularly hard in high-input farming and CS with low N use efficiency as well as in arable soil with high drainage (Strebel *et al*., 1989; Hall *et al*., 2001; Di and Cameron, 2002; Ramos *et al*., 2002). Other than rate, method and timing of N fertilizer application, several other factors such as soil texture, crop type, drainage system, soil water-table depth, quantity and method of irrigation, land use types, N residues in soil, precipitation

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characteristics and nitrate levels in irrigation water have significant impacts on nitrate leaching (Mclay *et al*., 2001). Nitrate leaching may also be a consequence of management practices in previous crops rather than current cultural practices (Singh and Skelon, 1978).

Field measurements must often be performed to assess the effects of water and agronomic management practices on nutrient transport. These measurements are costly and time-consuming. Water quality computer models are useful tools to predict the risk of agricultural chemicals' potential contamination to surface and ground water. A properly validated model provides a fast and cost effective way of estimating NO_3-N leaching under different agricultural management practices (Jabro *et al*., 2006). The number of non-point source agricultural models used to predict nitrate leaching through the root zone and into unsaturated soil zone has grown rapidly over two last decades. Computer models use nutrient transport equations and algorithms to assess water quality without the costly field measurements (Helwig *et al*., 2002).

Jabro *et al*. (2006) reported that LEACHM, NCSWAP and SOILN models have potential to predict annual NO_3-N leaching losses below the 1.2 m depth under continuous corn system. However, the overall performance and accuracy of SOILN model were worse than those of LEACHM and NCSWAP. The usefulness of physically based models has been demonstrated by Thorsen *et al*. (2000), who used readily available input data to simulate N leaching from an agriculture-dominated catchment in Denmark with promising results. In a small agricultural catchment in England, Birkinshaw and Ewen (2000) applied a physically based N transport modeling system (SHETRAN); The model was found to be useful for studying nitrate flows. The SOILNDB modeling system (Johnsson *et al*., 2002) is a physically-based management-oriented modeling system for quantification of nitrate leaching from arable land. Kyllmar *et al*. (2005) simulated N leaching from fields in an agricultural catchment to be 44 kg ha/year by SOILNDB, whereas measured N transport in the stream outlet was 40 kg N ha/year. The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model coupled to a GIS was used to evaluate the effect of different fertilization treatments on the total N leaching in a selected area of eastern Spain with intensive agriculture by De Paz and Ramos (2004).

The Decision Support System for Agrotechnology Transfer (DSSAT) cropping system model have been widely used over the 20 years by numerous researchers for many different purposes. Examples for model applications are; simulation of atrazine leaching in relation to water-table management (Gerakis and Ritchie, 1998), estimating nitrates and water in two soil (Beckie *et al*., 1995), large-scale simulation of wheat yields in a semi-arid environment (Chipanshi *et al*., 1999), nitrate leaching potential in Minnesota soil and predictions of nitrogen mineralized from cover crop residues (Quemada and Cabrera, 1995). Soltani and Hoogenboom (2007) and Soltani *et al*. (2004) used three crop models of DSSAT including CERES-Wheat, CERES-Maize and CROPGRO-Soybean to assess crop management options using actual and generated weather data.

During three last decades, synthetic fertilizer consumption has increased dramatically in Iran. Statistics indicates that Iran, Egypt and Turkey account for 75% of the fertilizer N consumption in the near east (Bijay *et al*., 1995). Gorgan, located at southeast of Caspian sea, is one of the most important regions for crop production in Iran where farmers use synthetic N fertilizers in large quantity, conventionally. In this region, rainfed (215,000 ha) and irrigated (150,000 ha) winter wheat crops include more than 50% of total arable lands (690,000 ha) and people, especially in rural zones, mainly rely on the groundwater for drinking water supply. Unpublished results of nitrate concentration measurements in recent years have indicated that nitrate levels in some wells is more than allowed maximum pollutant concentration in this region. Thus, we studied the effects of different scenarios of N fertilizer application and soil profiles on the nitrate leaching under rainfed and irrigated winter wheat using DSSAT cropping system model.

MATERIALS AND METHODS

Model Description

The Decision Support System for Agrotechnology Transfer Cropping System Model (DSSAT-CSM) have been in use for the 20 years by many researchers worldwide. This package incorporates models of 16 different crops including CERES-Wheat with software that facilitates the evaluation and application of the crop models for different purposes (Jones *et al*., 2003). The DSSAT-CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon and nitrogen that take place under cropping system over time. The Primary modules are for weather, soil, plant, soil-plan-atmosphere interface and management components. Collectively, these components describe the time changes in the soil and plants that occur on a single land unit in response to weather and management (Jones *et al*., 2003). The soil module integrates information from four sub-modules include; soil dynamics, soil temperature, soil water and soil nitrogen and carbon. The last sub-module computes soil nitrogen and carbon processes, including organic and inorganic fertilizer and residue placement, decomposition rates, nutrient fluxes between various pools and soil layers. Soil nitrate and ammonium concentrations are updated on a daily basis for each layer.

CERES-Wheat module is an individual plant growth module that simulates wheat phenology, daily growth and partitioning, plant nitrogen and carbon demands, senescence of plant materials, etc. The model also have management operations module included Irrigation and fertilizer and other sub-modules.

The DSSAT models require the minimum data set for model operation. The contents of such a dataset have been defined based on efforts by workers in IBSNAT and ICASA (Hunt *et al*., 2001). They encompass data on the site where the model is to be operated, on the daily weather during the growing cycle, on the characteristics of the soil at the start of the growing cycle or crop sequence and on the management of the crop (e.g., tillage, seeding, fertilizer applications, irrigation, harvesting) (Jones *et al*., 2003).

Required weather data encompass daily records of total solar radiation incident on the top of canopy, maximum and minimum air temperature above the crop and rainfall. The DSSAT-CSM requires information on the water holding characteristics of different soil layers. It needs a root weighting factor that accommodates the impact of several adverse soil factors on root growth in different soil layers, such as soil pH, soil impedance and salinity. Additional soil parameters are needed for computing surface runoff, evaporation from the soil surface and drainage (Ritchie, 1972). Initial values of soil water, nitrate and ammonium are needed as well as an estimate of the above- and below-ground residues from the previous crop. Typical crop management factors include tillage, planting date, planting depth, row spacing, plant population, fertilization, irrigation, inoculation and harvesting (Jones *et al*., 2003). The model also requires coefficients for the genotypes involved (Hunt, 1993; Ritchie, 1993).

Site and Scenario Description

The experiment was conducted in Gorgan, Iran during 2005-2007 years. Gorgan Region with an area of 20311.6 km^2 is situated at Southeastern Caspian Sea and Northeast of Iran. The region is located between 36°44' and 38°05' N latitudes and 53°51' and 56°14' E longitudes. Total arable lands area is about 685,000 ha. Main crops in this area are winter wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), rice (*Oryza sativa* L.), cotton (*Gossypium hirsutum* L.), soybean (*Glycine max* (L.) Merr.), oilseed rape (*Brassica napus* L.) and sunflower (*Helianthus annuus* L.). Rainfed (215,000 ha) and irrigated (150,000 ha) winter wheat include more than 50% of arable lands. The long-term mean of annual rainfall is 433 mm. Rainfall is not distributed evenly along the year and usually a relatively

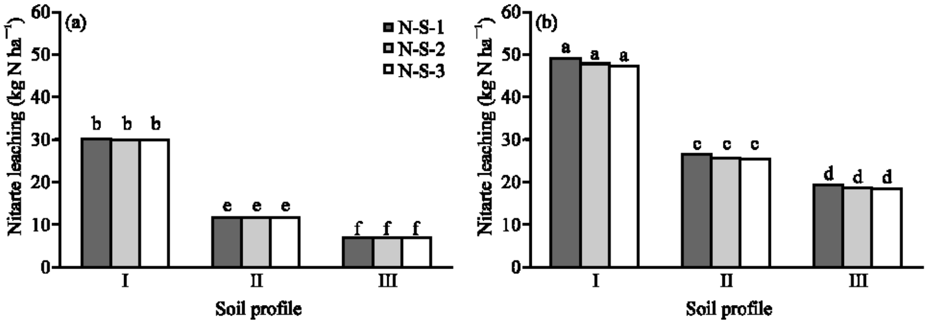

Fig. 1: Nitrate leaching rates in three soil profiles and 3 N use scenarios under rainfed and supplemental irrigation cropping system. Means labeled with the same letter(s) are not significantly different as determined by Least Significance Difference (LSD) at $\alpha = 0.05$, (a) rainfed and (b) irrigated

wet and cold season (autumn, winter and early spring) is followed by a dry and warm season (Fig. 1). The amount of annual precipitation was fluctuated from 260-668 mm during simulation period (1961-2006). Monthly maximum and minimum rainfall occurs in March (76.5 mm) and July (20.2 mm), respectively (Fig. 1). Based on the long-term means, the maximum (22.4 MJ m^2 day^{-1}) and minimum (8.2 MJ m^2 day^{-1}) solar radiation were occur in June and December, respectively (Fig. 1). Soil of this area are usually deep and characterized to have relatively high silt and clay and low sand percentages. The soil have a lose nature. The dominant soil textures are loam, silt loam, silty clay loam, clay loam.

Simulations were performed using three SLPs and three conventional N-Ss under two common wheat CSs including rainfed and irrigated and management practices similar to what farmers do, traditionally.

Three SLPs were defined according to the analysis of numerous soil samples were taken from 16 wheat fields around Gorgan (36°85' N latitude and 54°27' E longitude) by researchers during 2006-2007 growing season to 120 cm depth and hundreds soil samples were collected from this region by soil analysis laboratory of Golestan Agricultural Organization during the last years. Some physical and chemical characteristics of three SLPs used in this study to simulate nitrate leaching are given in Table 1. Three N-Ss conventionally used by the area farmers were considered. The amounts (kg N ha^{-1}) of fertilizer-N used in N-S-1, N-S-2 and N-S-3 were 165 (23 as urea and 27 as diammonium phosphate applied pre-plant and 46, 35 and 34 as urea applied topdress at 65, 95 and 125 days after planting), 122 (23 as urea and 18 as diammonium phosphate applied pre-plant and 35, 23 and 23 as urea applied topdress at 65, 95 and 125 days after planting) and 96 (27 as diammonium phosphate applied pre-plant and 46 and 23 as urea applied topdress at 65 and 95 days after planting), respectively. The supplemental irrigations were considered to do at 125 (60 mm) and 140 (70 mm) days after planting. Remained residues from previous crop (soybean) were considered to be 1800 kg ha^{-1} that returned to soil after harvesting by a moldboard plow. Plant populations at seeding and emergence were defined 500 and 350 m^{-1}, respectively. Row spacing was 15 cm and seeding depth was 4 cm. Seeding date was 6 December for all years, constantly. All scenarios and crop management practices were the same for all simulation years (i.e., 1961-2006). Long-term and reliable daily weather data were obtained from Gorgan meteorological station located near Gorgan City. Tajan, a common bread wheat cultivar seeded in the area during the recent years, was defined as a new genotype in CERES-Wheat model. Genetic coefficients were calculated using the results of several studies carried out in Gorgan conditions. CERES-Wheat model had been tested on experimental data sets and demonstrated to work well in this region (Soltani *et al*., 2004; Soltani and Hoogenboom, 2007). Hence, for the purpose of this paper we didn't test it again.

Table 1: Some physical and chemical characteristics of three soil profiles used to estimate nitrate leaching from winter wheat fields

						Vol. WC (m^3 m^{-3})		
Soil profile	Layer depth (cm)	Sand (%)	Clay (%)	Silt (%)	Bulk density (g cm^{-3})	-1.5 MPa	-0.03 MPa	Saturated
I	0-15	43	22	35	1.40	0.134	0.264	0.472
	15-30	41	24	35	1.38	0.142	0.273	0.478
	30-60	25	31	44	1.31	0.172	0.328	0.504
	60-90	13	35	52	1.27	0.194	0.364	0.520
	90-120	10	36	54	1.26	0.200	0.373	0.523
II	0-15	27	28	45	1.33	0.157	0.312	0.497
	15-30	25	31	44	1.31	0.172	0.328	0.504
	30-60	14	36	50	1.27	0.200	0.368	0.520
	60-90	11	45	44	1.23	0.258	0.420	0.535
	90-120	10	47	43	1.22	0.271	0.432	0.538
III	0-15	14	34	52	1.28	0.188	0.358	0.517
	15-30	13	36	51	1.27	0.200	0.390	0.521
	30-60	11	39	50	1.25	0.219	0.387	0.527
	60-90	9	45	46	1.23	0.258	0.422	0.536
	90-120	9	48	43	1.22	0.278	0.438	0.540

Soil profile	Layer depth (cm)	#Avail. water (m_3 m^{-3})	*Sat.hydr conduct. (m day^{-1})	Organic carbon (%)	Tot. N (%)	NO_3 (ppm)	NH_4 (ppm)
I	0-15	0.130	0.164	1.33	0.10	22	2.2
	15-30	0.131	0.137	1.13	0.10	18	1.8
	30-60	0.155	0.098	0.74	0.06	10	1.6
	60-90	0.170	0.096	0.31	0.04	7	1.3
	90-120	0.172	0.097	0.20	0.02	5	1.1
II	0-15	0.154	0.119	1.33	0.10	22	2.2
	15-30	0.155	0.098	1.13	0.10	18	1.8
	30-60	0.168	0.089	0.74	0.06	10	1.6
	60-90	0.162	0.065	0.31	0.04	7	1.3
	90-120	0.160	0.063	0.20	0.02	5	1.1
III	0-15	0.170	0.100	1.33	0.10	22	2.2
	15-30	0.169	0.091	1.13	0.10	18	1.8
	30-60	0.169	0.082	0.74	0.06	10	1.6
	60-90	0.164	0.068	0.31	0.04	7	1.3
	90-120	0.160	0.063	0.20	0.02	5	1.1

#Available water, *Saturated soil hydraulic conductivity

Statistical analysis was performed according to General Linear Procedures (SAS, 1989). Analysis was conducted as a randomized completely design as factorial experiment in which each scenario was considered as a treatment and each year as a replication.

RESULTS AND DISCUSSION

Nitrate leaching in SLPs, N-S, Css and years included an extensive range between 0 and 135 kg N ha/year. The overall average of estimated nitrate leaching in 18 scenarios during 1961 to 2006 was 23.6 kg N ha/year. Forty six year mean rates of N-leached in examined scenarios varied from 6.89 to 48.93 kg N ha/year (Fig. 1). The CS and SLP had significant effects (p=0.01) on the nitrate leaching, but the effects of N-S and interactions between CS, SLP and N-S were not significant, statistically. In RFDCS, the mean of NO_3 leaching was 16.20 kg N ha/year while in IRRCS it was 30.96 kg N ha/year. The difference between rainfed and irrigated CSs for N-leached rate to beneath 120 cm depth was significant, statistically (Fig. 1, Table 3). In general, nitrate leaching is happened where there is NO_3-N (leaching-susceptible form of nitrogen) in the soil as well as enough water flux down the soil profile to move it to the lower depths of soil profile. In this study, the N-S and thus, accumulation of NO_3-N in soil profile were the same in both CS, but two CSs were different for soil water content. Rainfed winter wheat is completely depended to rainfalls during growing season and

Table 2: *Means of Cumulative Nitrogen Leached (CNL), Cumulative Drained Water (CDW), Cumulative Nitrogen Uptake (CNU) by plant, Biological Yield (BioYld), Grain Yield (GrnYld, maXimum LAI (LAIX) and in rainfed and irrigated cropping systems, 3 N use scenarios and 3 soil profiles

Treatments	CNL (kg ha^{-1})	CDW (mm)	CNU	BioYld	GrnYld	LAIX	INAM (kg ha^{-1})
			--------------(kg ha^{-1})-----------------				
Crop system							
Rainfed	16.20^{b}	53.48^{b}	196.84^{a}	15101.48^{b}	5197.78^{a}	3.91^{a}	121.60^{a}
Irrigated	30.96^{a}	98.40^{a}	196.94^{a}	17359.42^{a}	5234.26^{a}	3.91^{a}	110.42^{b}
LSD ($\alpha = 0.05$)	2.58	7.42	2.58	245.46	82.97	0.06	3.17
N-Scenario							
N-Scenario1	23.94^{a}	75.96^{a}	198.76^{a}	16316.87^{a}	5250.61^{a}	3.95^{a}	137.84^{a}
N-Scenario 2	23.52^{a}	75.94^{a}	196.89^{ab}	16234.57^{a}	5217.99^{a}	3.91^{a}	115.17^{b}
N-Scenario 3	23.28^{a}	75.93^{a}	195.02^{b}	16139.92^{a}	5179.47^{a}	3.87^{a}	95.00^{c}
LSD ($\alpha = 0.05$)	3.16	9.09	3.49	300.78	101.64	0.07	3.63
Soil profile							
Soil profile I	39.01^{a}	123.50^{a}	194.48^{b}	16106.55^{a}	5157.69^{b}	3.86^{b}	111.45^{c}
Soil profile II	18.77^{b}	61.64^{b}	197.11^{ab}	16255.95^{a}	5224.66^{ab}	3.92^{ab}	116.12^{b}
Soil profile III	12.96^{c}	42.68^{c}	199.09^{a}	16328.86^{a}	5267.71^{a}	3.95^{a}	120.46^{a}
LSD ($\alpha = 0.05$)	3.16	9.09	3.49	300.78	101.64	0.07	3.63
Mean	23.58	75.94	196.89	16230.45	5216.02	3.91	116.01

*In each column, means labeled with the same superscript letter(s) are not statistically different as determined by Least Significant Difference (LSD) at $\alpha = 0.05$

Table 3: Cumulative Nitrogen Leached (CNL), Cumulative Drained Water (CDW), Cumulative Nitrogen Mineralized (CNM), Cumulative Ammonia-Nitrogen Volatilized (CANV) and Inorganic Nitrogen At Maturity (INAM) in selected low-, medium- and high-rainfall years for soil profiles I and III under N-scenario 1 and rainfed cropping system

Soil profile	Rainfall group	Year	Rainfall (mm)	CNL (kg ha^{-1})	CDW (mm)	CNM (kg ha^{-1})	CANV (kg ha^{-1})	INAM (kg ha^{-1})
I	Low	1962	317	8.5	35	61.08	33.78	161.5
		1966	271	5.3	22	59.56	26.88	127.2
		1998	260	3.7	15	60.36	30.27	144.5
	Medium	1972	415	35.6	113	60.76	31.19	97.4
		1974	412	32.9	110	58.84	41.05	95.5
		1981	420	29.9	101	60.51	28.81	111.0
	High	1967	613	51.8	164	63.12	25.27	105.6
		1968	668	95.4	250	59.80	19.72	81.6
		1969	634	83.2	237	59.56	30.88	94.9
III	Low	1962	317	0.0	0	54.44	32.21	148.4
		1966	271	0.0	0	51.19	25.13	117.2
		1998	260	0.0	0	51.38	29.75	130.9
	Medium	1972	415	7.8	27	57.28	30.76	102.5
		1974	412	5.8	21	55.89	40.08	100.8
		1981	420	2.7	10	57.14	26.74	123.7
	High	1967	613	21.0	73	61.06	23.83	122.2
		1968	668	53.5	156	57.11	18.34	88.0
		1969	634	44.6	141	57.51	29.02	100.4

reserved water in soil before planting. The long-term average of annual rainfall in this area is about 430 mm of which more than 80% falls during 2 months before seeding and through growing season of winter wheat. However, it is increasingly warm and dry from April to end of wheat growing season. In contrast, two supplemental irrigations as amount as 130 mm (60 mm first and 70 mm second irrigation) resulted in greater soil water and drained water (Table 2) in IRRCS than rainfed. It should also be considered that irrigations were conducted during low precipitation and high evapotranspiration of growing season and after application of topdress nitrogen. Therefore, it can be concluded that increased N-leached in IRRCS was a result of greater soil water as a carrier for nitrogen transport from surface to below the root zone. These results are in agreement with the study of Gehl *et al*. (2005). They reported that management decisions that increase downward water flux, especially at the times when soil NO_3 concentration is high, enhance the risk of loss of NO_3 to below the crop root zone. Irrigated agriculture is implicated as a contributor to NO_3 contamination of surface and ground water (Burkart and James, 1999; Sogbedji *et al*., 2000).

To determine the relationship between soil water conditions and nitrate leaching, 9 low-, medium- and high-precipitation years from 1961-2006 were selected and nitrate leaching and some other nitrogen-related properties were simulated for the SLPs I (a relatively medium-textured SLP) and III (a relatively fine-textured SLP) under RFDCS conditions. The results of simulations demonstrated a relatively high correlation between the amounts of annual precipitation and cumulative N-leached during growing season of winter wheat (Fig. 2). In both SLPs, an increase in annual precipitation resulted in increasing N-leached rate (Table 3). As above mentioned, the soils of this region are often medium- to fine- textured and have relatively high water holding capacity (Table 1). In the other hand, soil water functions as a carrier in the process of nitrate movement to the beneath root zone. Therefore, when there is no or low drained water to the below root zone (such as low-rainfall years or years with light and repeated rains instead of heavy rains), nitrate leaching can be little (in light- and medium textured soil) or even zero (in high water maintaining capacity, fine-textured soil) (Table 3). Because of this reason, although both rainfall and drained water rates had a linear relationship with N-leached rate, determination coefficient of linear relationship between cumulative drained water and N-leached was very higher than of rainfall in each of 3 SLPs (Fig. 2, 3). However, this difference may be in part due to using annual rainfall data instead of rainfall during winter wheat growing season in the area. Consistent in this study, Gehl *et al*. (2005) reported that lower seasonal precipitation resulted in less soil water flux and less leaching losses in 2002 than 2001.

There were considerable differences between 3 high-rainfall years in both SLPs for N-leached rates to beneath 120 cm depth. In 1967, a high-rainfall year, cumulative nitrate leaching in SLPs I and III were 51.80 and 21.0 kg N ha^{-1}, respectively, while those of 1968, other high-rainfall year, were 95.4 and 53.5 kg N ha^{-1} (Table 3). This significant difference can be mainly attributed to differences in precipitation properties among years; In 1967, rainfalls were happened light and repeated, or in out of winter wheat growing season, while in 1968 or 1969 they were heavy and unrepeated and often through growing season. This resulted in more water flux from surface layers to lower layers (i.e., more

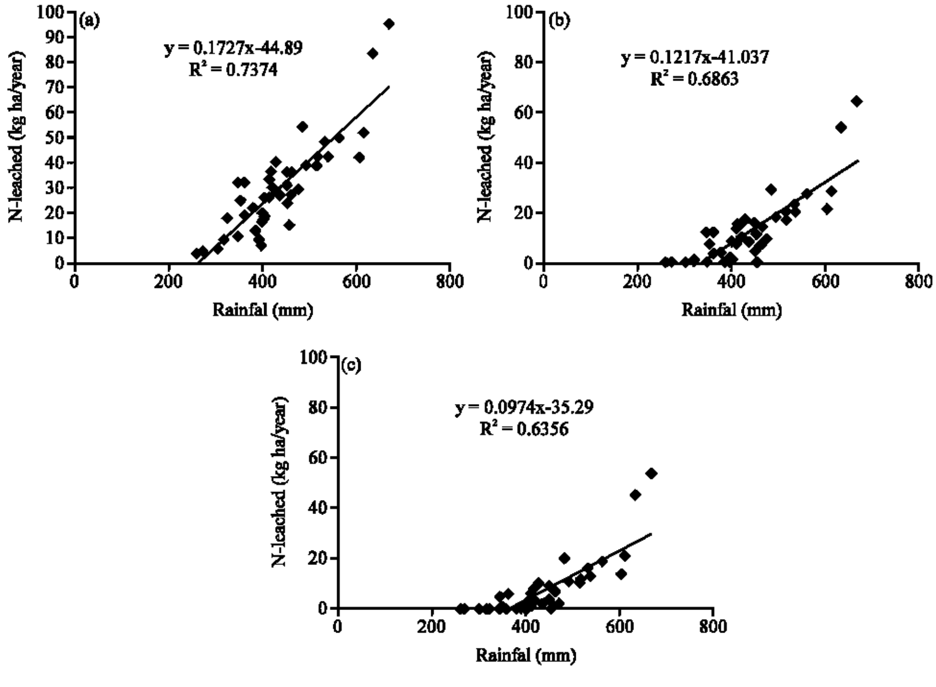

Fig. 2: Correlation between annual rainfall and N-leached rate in 3 soil profiles, (a) I, (b) II and © III

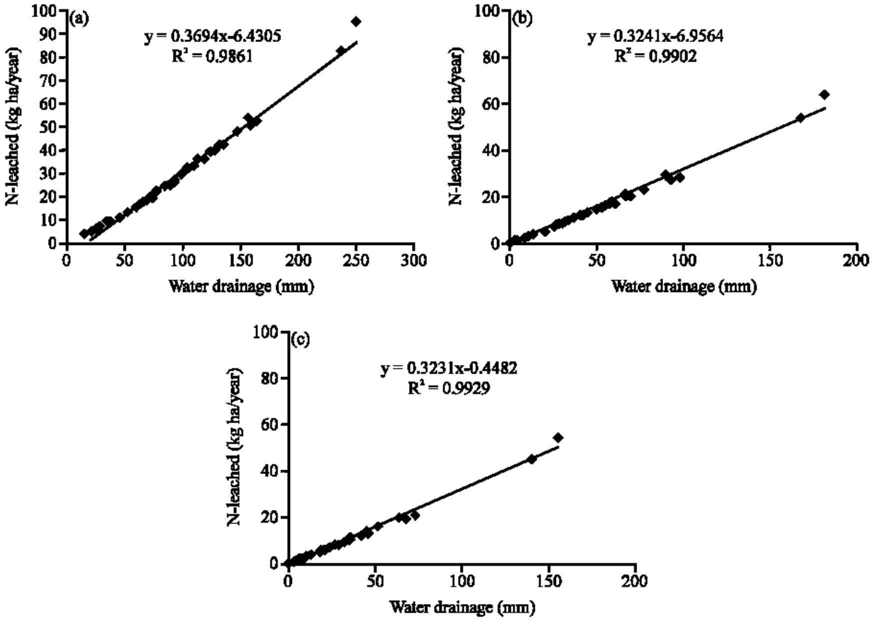

Fig. 3: Correlation between drained water and N-leached rate in 3 soil profiles

drained water) and more nitrate leaching in 1968 or 1969 than 1967. There was no given relationship between annual rainfall and N-mineralized or N-volatilized among selected 9 years (Table 3), but, a relatively adverse correlation between the rate of annual rainfall and inorganic nitrogen at maturity (INAM) was observed.

The results of simulations showed no significant difference between RFDCS and IRRCS for nitrogen uptake, maximum LAI and grain yield, while differences between two CSs for biological yield and INAM were significant, statistically (Table 2).

The averages of N-leached under N-S 1, 2 and 3 were 23.94, 23.52 and 23.28 kg N ha/year, respectively (Table 3), indicating no significant difference between three N-Ss for N-leached rate in each soil profile, statistically (Fig. 1). Conceptually, it seems that greater N fertilizer rates would lead to increased NO_3-N leaching potential, but this is not always the case. Nitrogen fertilizer rate has been shown to increase postharvest NO_3 content of the soil in several studies (Ottman and Pope, 2000). The amounts of Inorganic Nitrogen at Maturity (INAM) stage indicated that large quantities of inorganic nitrogen (mainly as NO_3-N) was remained at the end of growing season and that INAM was consisted to the amount of fertilizer N applied (Table 2). In addition, This may be partly due to relatively high mineral nitrogen (NO_3 and NH_4) content in the soil profile in the early growing season in this study (Table 1). In agreement with these results, several studies showed that nitrate leaching is often controlled predominantly by factors other than N rate and timing, such as growing season conditions, soil texture, soil moisture and crop (Sieling *et al*., 1997; Boman *et al*., 1995; Ottman and Pope, 2000). Nevetheless, long-term application of high N rates to wheat has been reported to increase levels in the subsoil for rainfed wheat (Westerman *et al*., 1994).

The comparisons of means for simulated drained water, grain and biological yields and LAI maximum showed no significant differences between N-Ss in each of soil profile (Table 2). Results of simulations provide evidence that overapplication of fertilizer N may lead to the accumulation of readily transportable nitrogen in soil (i.e. INAM) without any effect on growth and yield (Table 2); this nitrogen is ready to leaching during the same or next growing seasons. In fact, results showed that regardless of cropping system or soil profile type, the least fertilizer N application (i.e., N-S 3) was sufficient to obtain maximum winter wheat grain yield. Since this result may be a result of high initial rates of inorganic nitrogen in soil profile, it can be emphasized to consider initial rates of inorganic nitrogen in N fertilization.

A significant difference between three SLPs for cumulative N-leached rates was observed. The mean rates of N-leached to bellow 1.2 m depth in SLPs I, II and III were 39, 18.8 and 13 kg N ha/year (Table 2). In both CSs, the greatest nitrate leaching was belong soil profile I. In contrast, soil profile III had the lowest cumulative N-leached. The predicted rates of N-leached to beneath 1.2 m depth in SLPs I, II and III were 20, 12 and 7 kg N ha/year under RFDCS and 48, 26 and 19 kg N ha/year under IRRCS, respectively (Fig. 1). Increased N-leached from soil profile I can in large extent be due to physical properties of soil layers such as higher sand percent and hydraulic conductivity and lower soil water maintenance capacity in this profile. The layer to layer comparison indicates that all layers of soil profile I have a lighter soil texture (mainly because of more sand percent), a greater hydraulic conductivity coefficient and a lower capacity for water maintaining than similar layers of other two SLPs (Table 1). These characteristics resulted in the greater nitrate leaching from soil profile I than from II and III and II than III. In many studies, nitrate leaching from sandy soils have studied, but we simulated N leaching from medium- to fine-textured soil because they are dominant soils of this region. Such an apparent differences between SLPs were also observed for cumulative drained water; Total drained water from SLP- I during growing season was 123.5 mm, while that of SLPs II and III were 61.6 and 42.7 mm, respectively. Lembke and Thorne (1980) found that soil with a lower capacity to hold water and nutrients require large inputs of irrigation and fertilizer for optimum crop production, increasing NO_3 movement through the soil profile and loss by leaching.

SLPs were not significantly different for biological yield. Predicted grain yield in SLP III was more than SLP I, but the superiority of SLP I was not very important, economically. Results of mean comparisons indicated a significant difference between SLPs for INAM; as expected, INAM in SLP III (soil with lowest sand percent) was more than SLPs I and II and in SLP II was more than SLPs I (soil with highest sand percent. INAM had a correlation coefficient -0.42 with N-leached rate.

The comparison of N-leached rates in low-, medium- and high-rainfall years under RFDCS showed that in all years, N-leached rates from SLP I was considerably more than SLP III (Table 3). In SLP III, the means of nitrate leaching were 0, 5.4 and 39.7 kg N ha/year for low-, medium- and high-rainfall years, respectively, While those of SLP I were 5.8, 32.8 and 76.8 kg N ha/year. These results show that the difference between SLPs in medium- and high-rainfall were more than low-rainfall years; The amounts of precipitation in low-precipitation years were not enough to create a water flux to beneath 120 cm depth of SLP III. Thus no nitrate leaching was happened. Also, water flux to below the root zone in SLP II was little in these years that resulted in little nitrate leaching than medium- and high-precipitation years (Table 3).

In general, results of simulations indicated that nitrate leaching quantities from winter wheat fields of Gorgan region under common management practices are significant and include at least 20% of N fertilizer used by farmers. A noticeable fraction of these large quantities of N-leached to below the root zone can finally be transported to groundwater and increase nitrate concentrations. Based on these results, soil characteristics and soil moisture conditions are two main factors determining the nitrate leaching from surface to lower layers of soil profile. This means that if the soil of this region are coarse-textured and have a higher hydraulic conductivity, or, if the rainfalls are heavier or wheat fields are irrigated more than two times, especially during the last 3 months of growing season, then, it can expected that nitrate leaching be very more than these obtained rates. According to these results and that drinking and irrigation water supply are mainly rely on the groundwater in Gorgan Region, it seems necessary to monitor nitrate pollution of water resources and to find effective ways to minimize nitrate nitrogen losses from wheat and other crop fields, environmentally and economically. Also, considering nitrate levels in water resources to calculate required N-fertilizer in crop production systems can be recommended.

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